

CROP RESIDUES

Soil Surface Property and Soybean Yield Response to Corn Stover Grazing

Justin T. Clark, James R. Russell,* Douglas L. Karlen, P. L. Singleton, W. Darrell Busby, and Brian C. Peterson

ABSTRACT

Farmer concern that compaction and/or surface roughness caused by winter grazing of corn (*Zea mays* L.) crop residues may reduce subsequent soybean [*Glycine max* (L.) Merr.] yield prompted this 3-yr, on-farm study near Atlantic, IA. Two 19-ha fields with Marshall silty clay loam (fine-silty, mixed, superactive, mesic Typic Hapludolls), Minden silty clay loam (fine-silty, mixed, superactive, mesic Aquic Hapludolls), Corley silt loam (fine-silty, mixed, superactive, mesic Argiaquic Argialbolls), and Colo silty clay loam (fine-silty, mixed, superactive, mesic Cumulic Endoaquolls) soils managed in a corn-soybean rotation were chisel-plowed and split into four replicate blocks of six paddocks. Five paddocks within each block were grazed in consecutive 4-wk intervals at a stocking rate of 3.7 cows ha⁻¹ while the sixth provided a nongrazed control. Following each grazing season, two blocks were disked, and two received no-tillage before soybean planting. Soil bulk density, aggregate stability, moisture content, penetration resistance, surface roughness, residue cover, soybean plant population, and yield were evaluated for each grazing by tillage treatment. Soil bulk density was not affected, but penetration resistance to a depth of 10 cm increased in paddocks grazed in October and November. Cattle grazing had no effect on subsequent soybean plant population, but yield decreased with increased soil penetration resistance ($r^2 = 0.36$). As the proportion of time soil temperature was below 0°C during the grazing period increased, soybean yield increased ($r^2 = 0.72$). Effects of grazing corn crop residues on subsequent soybean yield will be minimal if grazing is restricted to periods when soils are frozen or if the soil is disked before soybean planting.

PROVIDING FEED can account for over half of the total cost of managing a beef cow herd (Lawrence and Strohbehn, 1999), so many Midwestern farmers graze corn crop residues to decrease their expenses. However, there is some concern among producers that cattle trampling can negatively affect soil physical properties by increasing soil compaction and subsequently decrease crop yields.

For row crops, it has been shown that soil structure changes due to high axle loads can cause significant reductions in crop yield (Flowers and Lal, 1998). Compaction and the resultant increase in bulk density decrease total pore space, causing poor aeration (Lal, 1996),

reduced water infiltration rate (Wallatt and Pullar, 1983), delayed plant emergence (Flowers and Lal, 1998), impaired root growth (Voorhees, 1992), and reduced transport of oxygen and nutrients (Scholefield et al., 1985). The severity of compaction depends upon soil moisture content at the time of traffic (McCormack, 1987), with its persistence increasing on high-clay soils (Lal, 1996).

In New Zealand and Australia, the effects of animal compaction (pugging) on pasture have been examined (Greenwood et al., 1997; Wallatt and Pullar, 1983), but very little information is available on the effects of grazing on row crop ground. The ground pressure exerted by a grazing cow may be similar to that of harvest implements while standing but will increase when walking because of weight redistribution and the kinetics of motion (Greenwood et al., 1997). Estimates of ground pressure range from 123 kPa for a mature beef cow standing still (Betteridge et al., 1999) to 490 kPa applied by a 500-kg cow walking (Scholefield et al., 1985). These values are compared to an estimated 138 kPa of pressure applied by a combine at harvest (Stewart Melvin, personal communication, 2003).

Under pasture conditions, grazing has been shown to have varying effects on compaction, depending on soil texture (VanHaveren, 1983), soil water content at time of grazing (Scholefield et al., 1985), and stocking density (Warren et al., 1986). However, because most studies relating soil compaction and cattle grazing are conducted during summer months, their results may not be relevant to grazing corn crop residues when soils are frozen. Our objectives were to evaluate the effects of grazing corn crop residues at different periods during the winter on soil physical properties and subsequent soybean yields when planted following disking or with no-tillage practices. We hypothesized that an increase in the proportion of time the soil temperature was below 0°C during a grazing period would minimize soil disruption and compaction, preventing a reduction in subsequent soybean yield.

MATERIALS AND METHODS

Experimental Design

A 3-yr field study was initiated in 1999 near Atlantic, IA (41°4' N, 95°0' W), by dividing a 39-ha field into two fields for a corn-soybean rotation. To initiate the experiment under equal soil physical conditions, both fields were prepared in Year 1 by chisel plowing at a depth of approximately 20 cm and disking one time. Corn was planted in 76-cm rows using a 16-row Kinze 3600¹ (Kinze Manufacturing, Inc., Williamsburg,

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IA) planter equipped with no-till coulters to attain a plant density of 69 160 plants ha^{-1} while soybean was drilled in 18-cm rows using a 10-m-wide John Deere air seeder (John Deere and Co., Moline, IL) to attain a plant density of 494 000 ha^{-1} . Corn grain was harvested with a combine equipped with a straw spreader (New Holland TR 99, CNH America LLC, New Holland, PA). After grain harvest, each cornfield was divided into four 4.86-ha blocks using a hand-held GPS. Electric fence was used to subdivide each block into six paddocks. A lane to a common watering and supplementation site was established within each block. One paddock in each block was randomly selected as a nongrazed control while the remaining five were grazed in 4-wk intervals (total of 20 grazing weeks) to evaluate the interaction between corn residue grazing and weather conditions on soil properties and subsequent soybean yield. Before grazing, twelve 0.84- m^2 grazing exclosures were placed along two transects at approximately 27.4-m intervals within each grazed paddock for comparison of soil physical properties in grazed and nongrazed areas. To obtain a split-split plot design with grazing period as the main effect and postgrazing/pre-soybean planting tillage as the secondary effect, two of the four blocks were randomly selected for no-till while two were disked before planting soybean to reduce the surface soil effects of cattle trampling should they occur.

On 18 Oct. 1999 (Year 1), 16 Oct. 2000 (Year 2), and 23 Oct. 2001 (Year 3), the first paddock to be grazed in each block was stocked with three mature, pregnant Angus cows (mean body weights: 620 ± 46 , 594 ± 43 , and 605 ± 50 kg for Years 1, 2, and 3, respectively) at a stocking rate of 3.7 cows ha^{-1} . Large round hay bales were provided to the cattle when deemed necessary by the herdsman.

Environmental Measurements

Throughout the grazing period, data loggers (HOBO series H8, Onset Computer Corp., Bourne, MA) were used according to instructions for recording soil temperatures at a depth of 10 cm every 30 min at two locations per block. All damaged data loggers or erroneous data were discarded, and the remaining measurements were averaged for each 30-min measurement. Daily precipitation was obtained from the Atlantic, IA, station of the National Climatic Data Center.

Soil and Crop Residue Measurements

Soils were core-sampled to a depth of 50 cm at 12 locations in each paddock before grazing in Years 1 and 2 for visual classification of the soil map unit, subsoil depth, and clay content (Richard Bednarek and Mark LaVan, NRCS, personal communication, 2000). Because the subfields used for grazing in Year 1 were reused in Year 3, soil classification, subsoil depth, and clay content for each paddock were assumed to be the same. Each year, an additional 12 soil samples per paddock were collected from between rows using a 32-mm-diam. soil probe to the depth of 0 to 10 and 10 to 20 cm to determine soil bulk density and moisture content 1 d before grazing. Soil water content was determined by oven-drying a subsample at 105°C for 48 h. Bulk density was then estimated by correcting the entire sample mass to an oven-dry weight and dividing by the sample volume (3860 cm^3) for the 12 cores collected from each plot (Arshad et al., 1996). Upon completion of the grazing season in the first week of March, another set of samples was collected for the same depth increments from between rows, both within and 4.5 m outside of each grazing exclosure. Soil water content and bulk density were determined again. To account for variation in soil properties between paddocks, postgrazing soil bulk density measurements for each exclosure

were expressed as a ratio of the outside to inside measurements at each depth. Soil bulk density ratios in the nongrazed control paddocks were assumed to equal 1.0. The same postgrazing soil samples were then used to determine wet aggregate stability, using a modified Yoder method. As with soil bulk density, aggregate stability was evaluated as a ratio of values outside to inside the exclosures, assuming nongrazed paddocks had a ratio of 1.0.

After each grazing season, simultaneous to bulk density and soil moisture sampling, soil penetration resistance was determined. At this time, no frost remained in the ground. The penetration resistance was recorded at 3.5-cm intervals using a penetrometer (Bush, mark 1, model 1979, Findlay-Irvine Ltd., Penicuik, Scotland) to measure the force required to push a rod with a 1.28-cm, 30° cone tip into the ground to a depth of 20 cm (3.5-cm intervals) at 12 locations between rows within and 4.5 m outside of the grazing exclosures. Because variations in soil moisture at the time of sampling can have a large effect on penetration resistance values, the soil moisture taken simultaneously to sampling was tested for differences between paddocks. For comparison to bulk density measurements, penetration measurements from 0 to 10 and 10 to 20 cm were averaged and expressed as a ratio of the measurements outside to inside each grazing exclosure. Once again, the ratio of the measurements outside and inside grazing exclosures was assumed to be 1.0 for the nongrazed control paddocks. Penetration resistance values outside the grazing exclosures are reported for each of the depth increments.

Soil surface roughness was measured each spring using two methods across rows within the grazed and control paddocks. Roughness was measured at 12 locations in each paddock as the percentage of change in the length of a 2-m-long chain forced to take the contour of the bare soil surface in a straight line (Saleh, 1993). Surface roughness was also measured as the standard deviation in the lengths of 41 pins spaced at 5-cm intervals on a 2-m-long pin meter at six locations in each paddock (Betteridge et al., 1999). Standard deviation of the pins was determined by image analysis of digital photographs using SigmaScan software (Jandel Scientific, San Rafael, CA).

Corn residue cover was measured at six locations in each paddock using the 100-point string method. Measurements were made at the initiation and termination of grazing and after soybean was planted in the spring.

Soybean Measurements

After emergence, plant population was measured by averaging the number of soybean plants on each side of a 91.4-cm stick from six random locations per paddock. Each count was multiplied by a factor of 9608 to calculate plants per hectare for the 18-cm rows. Soybean yields were measured for each paddock using a combine equipped with a global positioning system and RDS Pro Series 8000 yield monitor (RDS Technol. Ltd., Minchinhampton, Gloucestershire, United Kingdom). Soybean measurements from the lanes were excluded from data analysis.

Statistical Analysis

Using paddocks as the experimental unit, soil physical properties and postgrazing crop residue cover data were analyzed as a randomized block with the GLM procedure (SAS Inst., 1994) to test the effects of grazing period within a year. Post-planting corn residue cover, soybean emergence, and yield were analyzed as a randomized block design using the GLM procedure (SAS Inst., 1994) to test the main effects of grazing period and tillage as well as the interaction between the two

within each year. For variables with significant treatment effects, mean comparisons were conducted using Fisher's LSD at a significance level of 0.05 to determine the grazing period at which differences between the grazed and nongrazed paddocks occurred.

To quantify the effects of soil properties, corn residue, and environment on soybean yield, regression analysis was conducted for each tillage treatment and between tillage treatments for each year and among the 3 yr (SAS Inst., 1994). The effects of environment on soil penetration resistance and surface roughness were quantified using regression analysis, with the percentage of time that the soil temperature was below freezing as the independent variable. Specific maximum or minimum values for each dependent variable having a significant quadratic relationship were determined as the value of independent variable at which the first derivative of the regression equation equals zero.

RESULTS AND DISCUSSION

In all 3 yr, soil temperature remained above freezing for most of the first grazing period (Table 1). In the Years 1 and 3, soil temperature fell below freezing in December (Period 3) and rose above freezing in February (Period 5). In Year 2, soil temperature fell below freezing earlier than the first and third years and generally remained below freezing throughout the rest of the grazing periods. Monthly average precipitation was greatest during the first and last two periods of the season and usually lowest in December (Table 1).

Soil and Crop Residue Results

The distribution of soils within both halves of the 39-ha field was similar, with at least 70% of both fields being classified as Marshall silty clay loam. Also, neither clay content nor subsoil depth differed significantly among the paddocks selected to be grazed or nongrazed within a given year (data not presented). The average topsoil and subsoil clay content for Field 1 used in Years 1 and 3 were 219 and 330 g kg⁻¹, with a subsoil depth of 50.8 cm. The average topsoil and subsoil clay content for Field 2 used in Year 2 were 302 and 400 g kg⁻¹, with a subsoil depth of 59.4 cm. Soil water content before and after grazing did not differ among paddocks within any year. Mean pregrazing soil water contents at the 0- to 10- and 10- to 20-cm depths for Years 1, 2, and 3 were 210 and 230, 170 and 170, and 230 and 220 g kg⁻¹, respectively, while postgrazing soil moistures were 220

and 230, 260 and 250, and 240 and 240 g kg⁻¹, respectively.

Before grazing each year, the initial soil bulk densities showed no significant differences between paddocks selected to be grazed or nongrazed at either the 0- to 10- or 10- to 20-cm depths. Likewise, postgrazing soil bulk density ratios of grazed/nongrazed exclosures showed no increase in soil bulk density at the 0- to 10- or 10- to 20-cm depths, regardless of when cows were grazing corn residue within any of the 3 yr. The average postgrazing bulk density values for the 0- to 10- and 10- to 20-cm depth increments within grazed areas were 1.16 and 1.48, 1.18 and 1.42, and 1.22 and 1.38 g cm⁻³, respectively, for the 3 yr. Grazing corn residue also did not increase penetration resistance ratios at the 10- to 20-cm depth for any grazing period within any of the 3 yr. Average penetration resistance values at the 10- to 20-cm depths were 1275, 785, and 980 kPa for Years 1, 2, and 3, respectively. For the 0- to 10-cm depth, the penetration resistance ratio of grazed/non-grazed areas was significantly greater than 1 after certain grazing periods in all 3 yr. This effect is not surprising since penetration resistance is a more sensitive indicator of soil compaction than bulk density for some soils (Chanasysk and Naeth, 1995). In the second grazing period in Year 1, the penetration resistance ratio of grazed/non-grazed areas at the 0- to 10-cm depth was 1.29, indicating a 29% greater penetration resistance in paddocks grazed during the second period than in the nongrazed paddocks (Fig. 1). Similarly, penetration resistance ratios at the 0- to 10-cm depth for both the first and second periods grazed in Year 2 were 1.28 and 1.21. During Year 3, penetration resistance ratios at the 0- to 10-cm depth in the first, second, and fifth periods grazed were 1.44, 1.39, and 1.25, indicating a 44, 39, and 25% increase in penetration resistance in paddocks grazed during those periods.

To correctly use penetration resistance ratios as a measure of compaction, soil moisture at the time of sampling should be considered. Silva et al. (2002) reported that 69 to 75% of the variation in penetration resistance is attributed to soil moisture. Therefore, sample sites with different soil moisture contents cannot be compared for treatment effects. We found no significant differences in postgrazing soil moisture contents between grazed and nongrazed paddocks in any of the 3 yr. Regression analysis also indicated there was no

Table 1. Portion of the 4-wk grazing periods when soil temperature was below freezing and monthly precipitation.

Percentage of time that soil temp. was below freezing and monthly precipitation					
<u>1999–2000</u>					
Grazing initiation	18 Oct.	10 Nov.	8 Dec.	5 Jan.	2 Feb.
time < 0°C, %	0.0	0.0	3.4	100.0	72.5
Monthly precip., cm	2.7	2.4	1.8	0.8	3.8
<u>2000–2001</u>					
Grazing initiation	16 Oct.	13 Nov.	11 Dec.	8 Jan.	5 Feb.
time < 0°C, %	1.7	61.2	100.0	92.5	100.0
Monthly precip., cm	8.4	5.9	2.9	3.9	6.7
<u>2001–2002</u>					
Grazing initiation	23 Oct.	20 Nov.	18 Dec.	15 Jan.	12 Feb.
time < 0°C, %	2	0	79	99	69
Monthly precip., cm	0.6	6.8	0.6	3.4	2.6

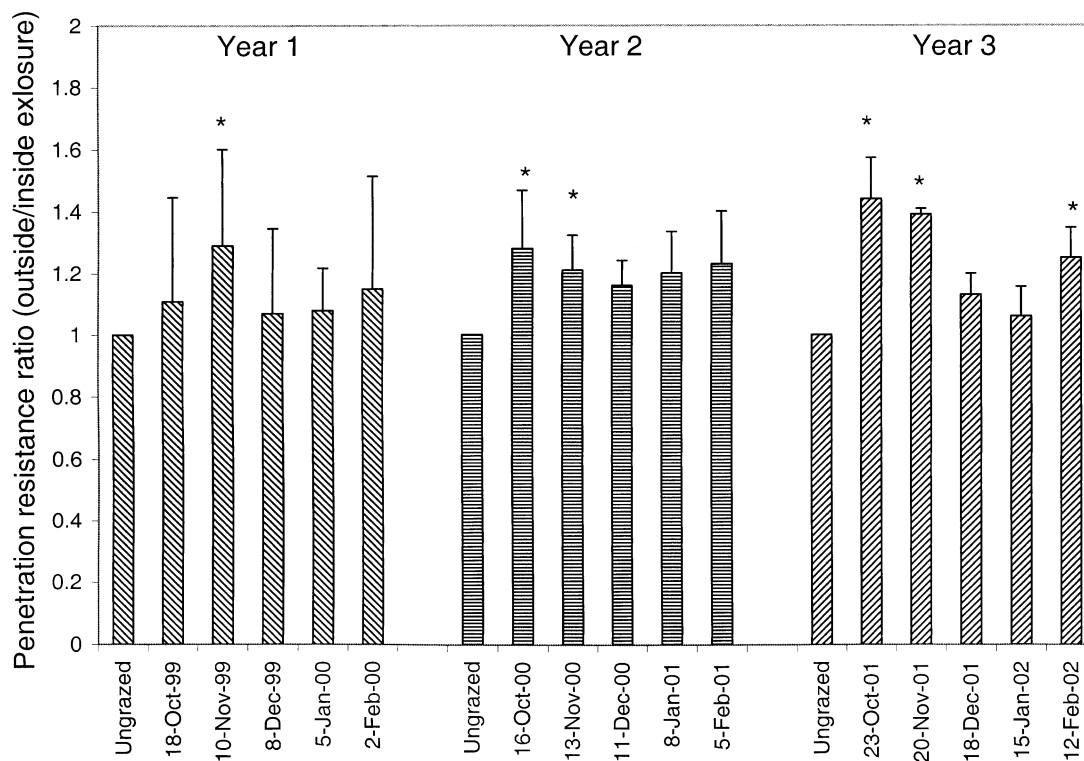


Fig. 1. Average penetration resistance ratio of measurements outside over inside grazing enclosure at a depth of 0 to 10 cm.

significant correlation between penetration resistance and soil moisture content within a given year. We, therefore, concluded that postgrazing soil moisture differences at the time of sampling were not the cause of variation in penetration resistance within years. As such, any effects on penetration resistance outside grazing enclosures, and therefore penetration resistance ratios, were assumed to be the result of trampling during grazing.

In Year 1, the initial soil moisture content of the upper 10 cm of soil before the start of grazing was 210 g kg⁻¹ soil. This moisture content plus the added 2.7 and 2.4 cm of precipitation during Grazing Periods 1 and 2 (without any appreciable evaporation or transpiration) plus the above-freezing soil temperatures could have produced conditions adequate for increased soil compaction during Grazing Period 2. This interaction between soil moisture content and above-freezing temperatures also explains why similar results were also observed for Grazing Periods 1 and 2 during Years 2 and 3. In the fifth grazing period of Year 3, soil temperatures also rose above freezing with the spring thaw. The increase in temperature resulted in snowmelt and increased soil moisture content compared with previous grazing periods. The resultant muddy conditions were very susceptible to compaction from trampling.

Root restriction depends primarily on the penetration resistance, and it is generally accepted that a resistance of 2 MPa in a dry soil essentially stops root growth (Unger and Kaspar, 1994). Wallatt and Pullar (1983) found on grazed pastures with loam soils an increase in penetration resistance by 20 to 30% over nongrazed areas was enough to diminish root growth of perennial ryegrass (*Lolium perenne* L.). Chanasyk and Naeth (1995) found

that as the forage-growing season progressed from May to August, the penetration resistance at the 10-cm depth more than doubled without an influence of grazing pressure. The average penetration resistance values for the 0- to 10-cm depths from both grazed and nongrazed paddocks in this study were 901, 371, and 583 kPa for Years 1, 2, and 3, respectively. This variation among years reflects the differences in precipitation (Table 1), emphasizing the importance of soil water content on penetration resistance between years. Based on work by H.M. Taylor (cited by Unger and Kaspar, 1994), the average penetration resistance for both the 0- to 10- and 10- to 20-cm depth increments was high enough to potentially affect root development. Furthermore, our sampling occurred during the first week in March, and although the penetration resistance may have exceeded 2 MPa by the end of the growing season and limited soybean yield in both grazed and nongrazed areas, no penetration measurements were taken during the soybean growing season to test this hypothesis.

Postgrazing wet aggregate stability ratios showed no increase or decrease at either depths in grazed areas for any of the 3 yr. The average aggregate stability for the 0- to 10- and 10- to 20-cm depths was 30 and 26, 24 and 28, and 25 and 22% for Years 1, 2, and 3, respectively. Based on current efforts to develop a soil management assessment framework (SMAF) for assessing soil quality (Andrews et al., 2004), aggregate stability values in this study were not low enough to warrant concern for decreased porosity or infiltration rate.

Soil surface roughness, measured with the 2-m chain, increased in paddocks grazed in the third and fifth periods in Year 1 and the second and fifth grazing periods

Table 2. Soil surface roughness as determined by standard deviation in pin length of a 40-pin meter and percentage reduction in chain length of a 2-m chain.

Soil surface roughness						
1999–2000						
Grazing initiation	nongrazed	18 Oct.	10 Nov.	8 Dec.	5 Jan.	2 Feb.
40-pin meter, cm [†]	1.1	1.2	1.3	1.3	1.2	2.1*
2-m chain, % [‡]	2.9	3.6	4.0	4.9*	3.0	9.5*
2000–2001						
Grazing initiation	nongrazed	16 Oct.	13 Nov.	11 Dec.	8 Jan.	5 Feb.
40-pin meter, cm	2.1	2.2	2.1	2.1	2.0	2.3
2-m chain, %	2.9	4.4	2.5	4.4	3.4	2.4
2001–2002						
Grazing initiation	nongrazed	23 Oct.	20 Nov.	18 Dec.	15 Jan.	12 Feb.
40-pin meter, cm	2.0	1.7	1.8	2.0	1.9	2.3
2-m chain, %	5.9	6.8	9.6*	7.2	8.6	11.6*

* Means in the same row with an asterisk (*) are significantly different from the mean of the control paddocks ($P < 0.05$).

[†] Standard deviation in pin length, cm.

[‡] Reduction in chain length, cm.

in Year 3 when compared with nongrazed control paddocks (Table 2). Soil surface roughness, measured with the 41-pin meter, showed similar results for the fifth month of grazing in Year 1 but not for the other three periods. The difference between the two soil surface roughness measurements is presumably caused by a difference in sensitivity. The 2-m chain method may be more sensitive because of the direct contact with the soil surface at every chain link, whereas the 41-pin meter only makes direct contact at the 41 pinpoints.

Betteridge et al. (1999) found on Aquic Dystric Euthrochrept soils in New Zealand that cattle grazing browntop (*Agrostis capillaries* L.) and ryegrass pastures caused substantial disturbances to the soil surface but little change in compaction. This effect was a result of high soil moisture content at the time of grazing. As water saturation increases, the soil becomes more susceptible to compaction; however, at water contents above the plastic limit, particle displacement is more likely to occur than compaction (Scholefield et al., 1985). This relationship may explain why surface roughness increased in the last period of Year 1, but there was no increase in the penetration resistance ratio. Water content of the soil may have been high enough to exceed the plastic limit, causing displacement of soil particles rather than compaction. Soil moisture was not measured on a daily basis in this project, but if the soil was above freezing, water content should have increased as accu-

mulated snow from previous periods melted. The increase in soil moisture may have caused soil particles to displace around the hoof rather than compact.

The amount of residue cover lost during grazing is influenced by several factors: size of the cattle, amount of residue present before grazing, tillage system, condition of field (soil moisture), and length of time cattle are on the field (Lesoin et al., 1996). In the current experiment, corn crop residue removal rates did not exceed 9%, a level that is lower than the average found by Lesoin et al. (1996) but well within their expected range of 5 to 25%. Corn residue removal rates on this project may have been slightly lower because of a difference in stocking rate or hay supplementation.

Soybean Establishment and Yield

Average soybean plant populations for the no-tillage and disked treatments were 249 000 and 203 000, 361 000 and 339 000, and 326 000 and 391 000 plants ha⁻¹ in Years 1, 2, and 3, respectively. These counts ranged from 41 to 79% of the desired plant population (494 000 plants ha⁻¹ or 200 000 plants ac⁻¹), but there was no significant difference between the grazed and nongrazed paddocks for any of the 3 yr. Discussions with our farmer cooperator revealed that the low stand establishment in Year 1 (41 and 50% of the desired stand) prompted him to add weight to his planter in subsequent years. This improved

Table 3. Soybean yields in the year following grazing of corn crop residue split by tillage method before soybean planting.

Soybean yields						
kg ha ⁻¹						
1999–2000						
Grazing initiation	nongrazed	18 Oct.	10 Nov.	8 Dec.	5 Jan.	2 Feb.
No-till	3288	3254	3200	3299	3322	3231
Tillage	3182	3335	3338	3245	3329	3411
2000–2001						
Grazing initiation	nongrazed	16 Oct.	13 Nov.	11 Dec.	8 Jan.	5 Feb.
No-till	3702	2989	2965	2860	2872	2819
Tillage	3323	3405	3294	3270	3124	3147
2001–2002						
Grazing initiation	nongrazed	23 Oct.	20 Nov.	18 Dec.	15 Jan.	12 Feb.
No-till	3012	2924	2775*	3045	3050	2989
Tillage	3138	3074	2875	3030	3071	2907

* Means in the same row with an asterisk (*) are significantly different from the means of the control paddocks ($P < 0.05$).

seed-soil contact and subsequent stand establishment. Disking before planting resulted in lower stand establishment in the first 2 yr but improved stand establishment in Year 3. Seasonal variation in soil moisture at planting and rainfall amount and intensity after planting (data not collected) presumably contributed to the lower-than-expected plant populations. Fortunately, soybean can generally compensate for poor stand establishment by developing more branches.

With or without preplant tillage, soybean yields were not significantly different for grazed and nongrazed paddocks in Years 1 and 2 (Table 3). Likewise, there was no significant difference after disking in Year 3. However, soybean yields from the no-tillage treatment in paddocks grazed during the second period (20 Nov. to 17 Dec. 2001) were 8% lower than in the nongrazed paddocks in Year 3. This was also one period when the penetration resistance ratio was significantly higher in the grazed than nongrazed paddocks (Fig. 1). When averaged across tillage treatments and for all 3 yr, there was no yield difference between grazed and nongrazed areas (2899 vs. 2892 kg ha⁻¹). This indicates that although compaction may be a problem in fields such as the one used for this study, the additional risk of a yield reduction due to winter corn crop residue grazing is minimal.

Penetration Resistance, Surface Roughness, and Yield Relationships

The proportion of time that soil temperature was below 0°C (i.e., frozen) when cattle were grazing had a greater effect on penetration resistance, surface roughness, and yield than either the grazing or tillage treatments, per se. For Years 2 and 3, there was a significant

quadratic relationship between penetration resistance and the proportion of time the soil was frozen (Fig. 2). Likewise, regression analysis for the 41-pin meter showed a significant quadratic relationship with the proportion of time the soil was frozen during Years 1 and 3 (Fig. 3). The analyses also show that penetration resistance and surface roughness were the greatest when the soil was frozen only 50 to 53% of the time [e.g., during the fifth period of Year 1 (Table 1)].

Soybean yield had an even stronger positive quadratic relationship to the proportion of time that soil temperature was below 0°C in Year 3 for the no-tillage system:

$$Y_{\text{no-tillage year 3}} = 2648 + 287X - 94X^2, r^2 = 0.72$$

where Y is the soybean yield, expressed as kg ha⁻¹, and X is proportion of time the soil temperature is below 0°C is low.

The highest soybean yields were achieved when grazing occurred while the soil was frozen 100% of the time. Using only Year 3, the regression analysis showed a strong negative linear relationship between penetration resistance ratio and no-tillage soybean yields:

$$Y_{\text{no-tillage year 3}} = 3023 - 214X, r^2 = 0.36$$

where Y is the soybean yield, expressed as kg ha⁻¹, and X is penetration resistance ratio.

Over the 3 yr, soybean yield decreased quadratically ($r = 0.38$) as surface roughness increased, but this relationship was caused primarily by differences in those variables among years. Therefore, the relationship between soybean yield and surface roughness appears to be unrelated to grazing.

Our regressions indicate that soybean yields were negatively affected when penetration resistance ratio

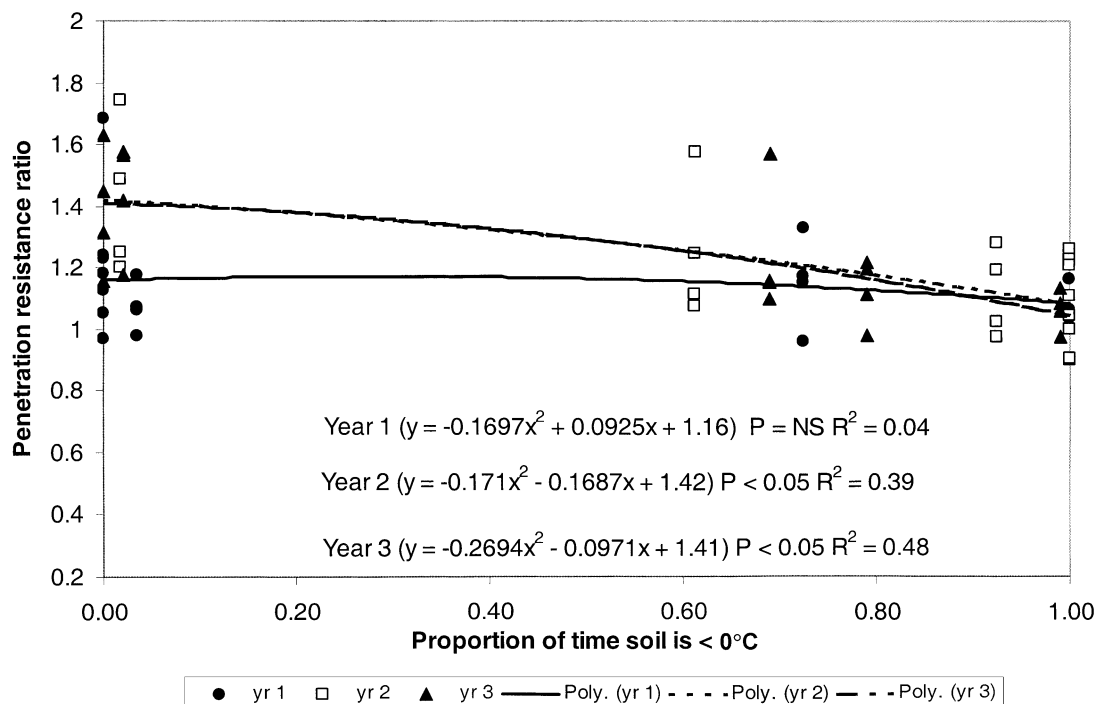


Fig. 2. Individual points and regression equations (polynomial) of the effect of proportion of time the ground is frozen in a 4-wk grazing period on penetration resistance ratio of 4.5 m outside over inside grazing enclosures.

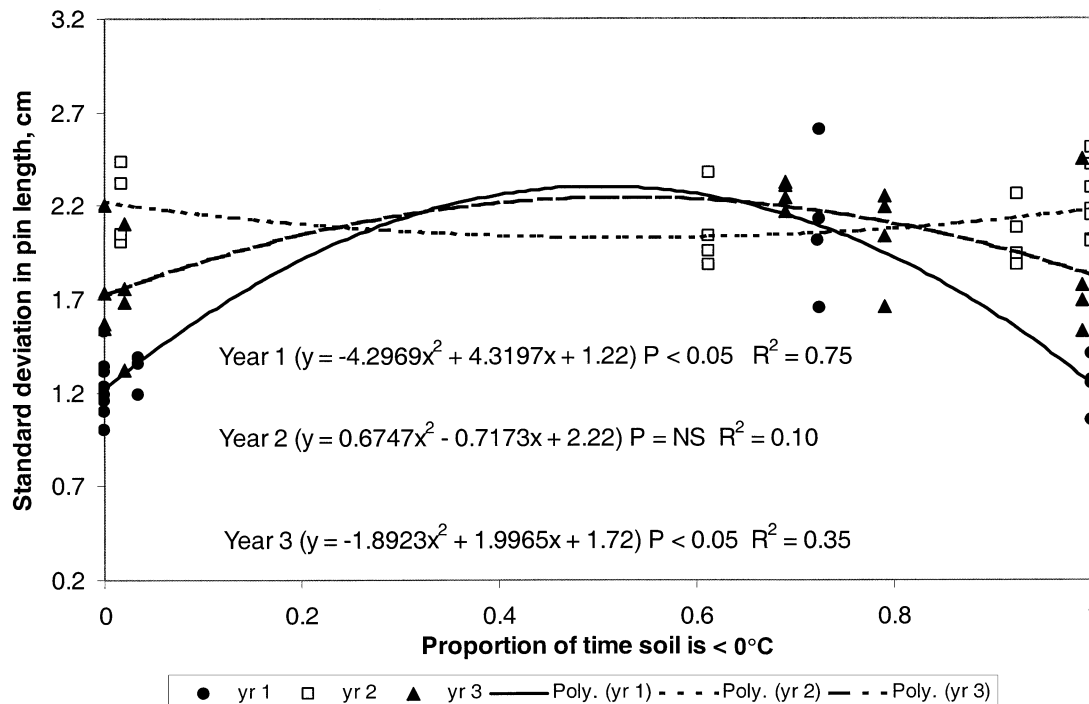


Fig. 3. Individual points and regression equations (polynomial) of the effect of proportion of time the ground is frozen in a 4-wk grazing period on soil surface roughness measured as standard deviation of pin length of a 41-pin meter.

was high and proportion of time when the soil temperature was below 0°C was low. The regressions also show that as the proportion of time the soil temperature was below 0°C decreased, penetration resistance ratio increased, suggesting that greater compaction occurred when the soil was not frozen. Likewise, soil surface roughness was maximized when the soil was frozen only 50% of the time. This would be consistent with the latter part of the grazing season when spring thaw causes muddy conditions. Therefore, soybean yields will be maximized and negative effects on soil properties will be minimized if corn crop residue grazing is restricted to periods of the winter when soil temperatures are below freezing. However, if practical and economical aspects of managing the cow-calf herd warrant grazing of cornstalks during the entire winter season, the data suggest any effects of grazing will be localized within the upper 10 cm and that they can often be mitigated with tillage before planting.

Implications

Cattle grazing on corn crop residue showed some negative effects on soil compaction and soil surface roughness. These effects were maximized when soil moisture content was adequate and soil temperature was above freezing. However, overall effects of crop residue grazing on soybean yield were small. There was only one instance of an 8% decrease for the no-tillage system when cattle were allowed to graze when soil temperatures were above freezing. Producers wanting to utilize corn crop residue grazing but unwilling to sacrifice soybean production should restrict grazing to periods when soil temperatures are below freezing or by implementing a pre-plant tillage practice. Overall, however, effects of grazing

corn crop residue on soybean yields were minimal, and the added benefits of utilizing corn stover as an inexpensive feed source should be considered.

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